

Manitoba
Water Stewardship



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Water Science and Management Branch
Ecological Services Division
Manitoba Water Stewardship

ASSINIBOINE RIVER AT BRANDON FLOOD RISK

Computation of the 100 Year Flood Discharge

Winnipeg, Manitoba
June, 2006

Surface Water Management



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D.E. Kelln (1)
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SYNOPSIS

The 100 year flood is commonly used for design of structures such as dikes, bridges and other water control works where flood damages and public safety are a concern. Manitoba Water Stewardship (MWS) has the responsibility of defining the 100 year flood magnitude, also referred to as the design flood, in terms of peak river discharge. A study under the Canada-Manitoba Flood Damage Reduction Program (FDR Study) in 1981 defined the 100 year controlled flood flow at Brandon as 22,400 cubic feet per second (cfs). This estimate was based on the recorded period of record for the Assiniboine River at Brandon which begins in 1906. The only significant flood since 1981 was that of 1995.

During the late 1990's Manitoba Water Stewardship began to use anecdotal historical floods to improve estimates of major flood flows and frequencies. Anecdotal floods are not measured but their magnitude has been estimated relative to that of a recorded flood. Including such floods extends the period of record and may involve events larger than those during the period of systematic records. This was done for the Red River in designing the expansion of the Red River Floodway. It was also done for the Assiniboine River at Brandon, where floods of 1882, 1902 and 1904 have been noted in newspapers of the day and in old reports.

Use of anecdotal floods in preparing design flood estimates involves some risk, since stages may not be well known. Peak flows need to be estimated since they have not been measured. It is therefore necessary to do a careful review of the anecdotal flood information to determine its reliability before it is used. Such a review was done for anecdotal floods at Brandon. Inclusion of the anecdotal floods at Brandon resulted in a natural 100 year flood flow estimate to 34,300 cfs.

Shellmouth Reservoir located on the Assiniboine River north of Russell, Manitoba has been operated since 1970. The design flood at Brandon must be based on controlled flows which consider the effects of the Reservoir on peak downstream flows. Controlled flows at Brandon were computed for the years prior to 1970 by simulating operation of the reservoir based on the guidelines which have been used in recent decades. Frequency analysis of controlled flows including anecdotal floods resulted in a 100 year flood flow estimate of 27,700 cfs, a 24 percent increase from the 1981 estimate.

INTRODUCTION

Frequency analysis for Manitoba streams is a task performed by hydrologists in the Surface Water Section of MWS. It consists of an analysis of past flood peaks to determine return periods or frequencies of various flood magnitudes. A flood with a 1% probability, also known as a 100 year flood, is expected to occur once during a 100 year period on average. It is different than flood forecasting which involves prediction of runoff and river levels for the next 30 days or so based on existing river flows, watershed conditions, and short term weather forecasts.

Prior to 1997, frequency analyses for the Assiniboine River at Brandon had been based on recorded peak flows from 1906 onward. During the late 1990's advances in frequency analysis techniques made it possible to properly include anecdotal historical floods in frequency analysis. The frequency analysis for Brandon was updated in 1997 to include flood flow estimates for 1882 and 1904. The analysis was further updated in 2002 to include the 1902 flood as well as improved estimates of controlled flows based on updated simulated Shellmouth Reservoir operations.

MWS became aware in 2005 that an updated 100 year flood estimate for Brandon would be required with respect to bridge design in the City of Brandon. A provisional frequency curve updated in 2002 was provided to Manitoba Transportation and Government Services (TGS) during the autumn of 2005 in response to their request for an update.

The provisional frequency curve was finalized in 2006 by adding controlled flood peaks up to 2005 and by reviewing the validity of the anecdotal flood information giving rise to a material change in the 100 year flood estimate. The results of the review and the updated 100 year flood estimate at Brandon are included in this report.

1. RECORDED AND REGULATED FLOOD PEAKS AT BRANDON

i) Monitoring of Levels and Flows at Brandon

Water Survey of Canada (WSC) has recorded daily water levels and has computed daily streamflows for the Assiniboine River at Brandon since 1906. Streamflows are based on periodic discharge measurements which are used to maintain stage-discharge relationships. The station was at 1st Street in Brandon until 1973 and has been at Grand Valley west of Brandon since

1974. There is little inflow from Grand Valley to Brandon, and attenuation due to channel storage is relatively minor and therefore flow records for these sites are compatible. The City of Brandon has monitored water levels at 1st Street from 1974 onward and Manitoba Water Stewardship has done periodic discharge measurements to maintain the stage-discharge relationship at 1st Street. However data for 1st Street after 1973 has not been published.

ii) Computation of Regulated Flows

Assiniboine River flows have been regulated by operation of Shellmouth Dam since 1969, significantly affecting annual peak flows at Brandon since that time. Peaks recorded prior to 1969 are unregulated. Since the design flood in the future will be regulated it is necessary to estimate the effect that regulation would have had on Brandon flood peaks prior to 1969.

Simulation of the Reservoir operation for the pre-regulation period was performed using monthly precipitation and forecast equations to simulate real time operations. Reservoir inflows were estimated from recorded flows for the Assiniboine River at Russell located somewhat downstream of the reservoir. Reservoir operations based on guidelines to meet objectives for flood control, downstream water supply and suitable reservoir levels were then simulated. The outflows were then routed to Brandon to determine peak flows which would have occurred under regulated conditions. Conversely natural flows were computed for the period from 1969 to 2005 based on flood routings without the presence of Shellmouth Dam.

The source of floodwaters can have a significant effect on the reduction of spring peak flows at Brandon due to operation of Shellmouth Reservoir. If a flood is primarily generated in the portion of the watershed upstream of Shellmouth Reservoir, as in 1923, the effect of regulation may be much larger than if the flood is generated primarily downstream of the reservoir, as in 1976. Simulation of Shellmouth Reservoir operation and its effects was more difficult for years prior to 1913 when the flow station at Russell did not exist and Qu'Appelle River flows were not available. Estimation of regulated flows at Brandon for years prior to 1913, including the anecdotal floods, was therefore approximated using a special procedure. Regulated and unregulated peak flows at Brandon from 1913 to 2000 were plotted as shown on Figure 2. The best regression fit between these data sets

was determined as shown by the red line. The grey lines are estimates of the lower and upper limits of the distribution. Conversion of the recorded flood peaks at Brandon to regulated peaks for the anecdotal floods and for events from 1906 to 1912 was done using the best fit (red) line on the chart. The yellow dots on the graph show the estimated regulated floods for these years.

iii) Natural and Regulated Flows

Mean daily peak flows for the Assiniboine River at Brandon are listed below. Observed flows are those listed under the 'Natural' column from 1906 to 1968 and under the 'Regulated' column from 1969 to 2005. Regulated flows from 1906 to 1968 and Natural flows from 1969 to 2005 are computed values. Observed peak stages at 1st Street in Brandon are included for the larger floods.

Year	Peak Discharge (cfs)		Mo/Day (observed)	Peak Stage (ft) *** (observed)
	*Natural	**Regulated		
1906	1320	1010	09/29	
1907	7487	5798	05/02	
1908	5615	4339	07/01	
1909	4202	3240	05/13	
1910	3637	2801	07/05	
1911	3708	2856	06/08	
1912	7134	5523	05/21	
1913	14900	8906	05/01	
1914	5862	4093	05/30	
1915	2461	2033	04/18	
1916	9147	8782	04/29	
1917	6500	4421	05/25	
1918	2709	2293	04/07	
1919	5332	4621	04/15	
1920	7663	5821	05/19	
1921	5156	5152	04/27	
1922	21295	15461	05/06	1177.7
1923	22990	14094	05/07	1178.2
1924	4732	4010	05/01	
1925	9111	9062	04/05	
1926	3955	2295	04/26	

4.

1927	17092	12087	05/05
1928	8087	5393	04/13
1929	4097	2415	05/01
1930	3479	2733	04/16
1931	1391	460	04/17
1932	2649	1882	04/18
1933	3479	2369	04/11
1934	4096	2904	04/14
1935	5827	4685	07/03
1936	10700	10196	04/15
1937	1741	1239	04/22
1938	2500	1770	03/28
1939	1670	1560	04/26
1940	826	653	04/25
1941	3330	2369	04/18
1942	6145	4393	04/09
1943	6604	5170	04/20
1944	2599	2407	07/08
1945	3118	2305	04/07
1946	7416	5820	04/09
1947	11089	9696	07/06
1948	15891	11515	05/07
1949	5120	4567	04/14
1950	5544	5667	07/16
1951	7557	6982	04/15
1952	4732	3187	04/16
1953	5827	5654	06/04
1954	12713	8865	07/09
1955	19105	14804	05/20
1956	15185	10644	05/18
1957	8582	5297	05/05
1958	4768	4582	04/06
1959	3161	1927	04/15
1960	8511	8095	04/16
1961	780	643	04/11
1962	2991	2344	04/28
1963	3172	2787	06/13
1964	4697	4393	04/18

5.

1965	7028	6278	04/20	
1966	5439	4688	05/06	
1967	5615	5507	04/21	
1968	2860	1957	04/12	
1969	12683	12713	04/17	
1970	8349	7840	05/16	
1971	9097	5014	04/18	
1972	9973	7805	04/20	
1973	970	865	04/05	
1974	14068	10912	04/22	
1975	14581	9217	05/01	
1976	22368	21789	04/18	1179.5
1977	1640	731	04/14	
1978	2777	2239	04/18	
1979	14774	11089	04/27	
1980	3578	3358	04/15	
1981	1016	922	03/04	
1982	4097	3814	04/22	
1983	8096	6710	04/26	
1984	2010	1236	04/02	
1985	8853	4979	04/11	
1986	7346	6816	04/03	
1987	8263	7946	04/11	
1988	4885	2860	05/16	
1989	877	982	04/05	
1990	8040	3814	04/27	
1991	3533	3602	04/09	
1992	5938	5297	04/24	
1993	2321	1278	07/15	
1994	3457	2303	04/10	
1995	29546	20483	05/09	1178.5
1996	12435	9747	04/22	
1997	12862	7946	04/20	
1998	4695	3443	04/11	
1999	9179	9111	04/07	
2000	3394	2949	07/16	
2001	17000	13137	04/29	
2002	2350	1949	04/21	

6.

2003	10100	6710	04/23
2004	4000	3125	06/16
2005	14600	13914	04/14

* Observed 1906-1968, Computed Natural 1969-2005

**Observed 1969-2005, Computed Regulated 1906-1968

***Stages are in feet above sea level adjusted to 1929 gsc

2. ANECDOTAL FLOOD PEAKS AT BRANDON

Floods are known to have occurred prior to the beginning of systematic data collection in 1906. The report "Conservation and Flood Control Assiniboine River" by PFRA (1952) contains information for large Assiniboine River floods which occurred in 1882, 1902 and 1904, including reports from newspapers of the day such as the Brandon Times. The Water Resources Division, Department of Resources and Development, presently known as Water Survey of Canada (WSC), reported the 1882 flood to be 5.5 feet higher than that of 1923. The Brandon Times reported the 1904 flood to be 34 inches lower than that of 1882 and the 1902 flood as being 25 inches lower than that of 1904. These peak flow estimates are based on anecdotal information and may be subject to error. However their inclusion was seen as providing a very significant improvement in the estimation of the 100 year flood at Brandon, provided that the reliability of the peak levels and computed peak flows for these floods could be substantiated. The following section of this report describes some investigations done to check on the validity of these estimates.

Peak stage and flow estimates for the anecdotal floods at Brandon are listed in the following table. The stages, based on the reported comparisons to the 1923 peak, have been converted to the standard 1929 datum adjustment by adding 0.53 feet as suggested by WSC.

	Estimated Peak Discharge (cfs)	Computed Regulated (cfs)	Mo/Day (observed)	Estimated Peak Stage (ft) (1929 adj)
1882	43000	31400	04/05	1183.7
1902	24700	19300	07/04	1178.8
1904	32300	25300	05/09	1180.9

3. REVIEW OF PEAK STAGES FOR 1882, 1902, 1904, 1922, 1923

Peak stages for the floods of 1882, 1902 and 1904 were not recorded but their relative magnitudes have been noted by observers and have been printed in the newspapers of the time, particularly in the Brandon Times, for-runner of the Brandon Sun. Since the peak stages for these floods are based on a comparison to the 1923 peak level, it is very important that the 1923 peak is correct.

A review of the 1923 peak stage revealed a potential discrepancy. The WSC daily water level data for 1st Street showed a peak level of 1178.23 feet. However the summary of flow measurements showed a peak level of 1179.73 feet. A similar difference of 1.5 feet was found for the 1922 peak stage. The detailed metering notes could not be found and therefore it was not possible for WSC to resolve this issue. However an alternate way of resolving this issue was found. The Canadian Pacific Railway (CPR) has a crossing about 1.2 miles downstream of 1st Street in Brandon, as shown on Figure 1. The CPR had referenced the 1922 peak water level to the bottom elevation of their rail at their crossing, which has not changed since 1922. The bottom rail elevation was surveyed by TGS at the request of MWS on June 5, 2006 and the 1922 peak level at the crossing was determined to be 1176.5 feet. The slope from the CP rail crossing to 1st Street is about 1.2 feet for a flood of 1922 magnitude, according to a backwater analysis from the 1981 FDR Study. This results in a 1922 peak level of 1177.7 feet at 1st Street. The 1923 peak level at 1st Street is 0.6 feet higher than the 1922 peak based on comparisons of either daily values or those from metering notes. This produces a 1923 peak level of 1178.3 feet at 1st Street, which is almost identical to the 1178.23 feet based on WSC daily data. Based on this evidence it was concluded that the correct level for 1923 is 1178.23 feet.

Based on the verified level for 1923, and the reported differences in the levels as noted earlier, the peak level at 1st Street for 1882 is 1183.73

feet, for 1902 it is 1178.81 feet and for 1904 it is 1180.90 feet. These levels may be rounded off somewhat as the differences in flood magnitudes given in the old reports are probably not exact.

As a further check on the peak levels for historic floods, profiles and cross-sections of the Assiniboine River in the Brandon area prepared by the Manitoba Hydrographic Survey, Department of the Interior, Water Power Branch in 1913 were obtained from PRFA archives. Plan #66722 shows the 1904 peak water level at 1st Street being 5.0 feet higher than that of 1913. The 1913 level observed by WSC was 1175.97 feet (1929 adj), which suggests that the 1904 level was 1180.97 feet. This corresponds very well with the 1180.9 feet estimated from the 1923 level based on newspaper reports. Since the levels for 1882, 1902 and 1904 were all related to the 1923 level via newspaper reports, independent verification of the 1923 and 1904 levels from the CPR and engineering drawings suggests that the estimated peak levels for 1882 and 1902 are also correct.

4. PEAK DISCHARGES FOR HISTORIC FLOODS

Peak discharges for the floods of 1882, 1902 and 1904 were computed by PFRA (1952) based on the commonly used Manning formula with estimates of the slope, cross-sectional area and hydraulic radius of the Assiniboine River channel as of 1923 in the area near 1st Street in Brandon. Using the peak water levels given in the previous section, the computed peak discharge for 1882 was 43,000 cfs, for 1904 was 32,300 cfs and for 1902 was 24,700 cfs.

It is difficult to check on these discharges using river hydraulics since the physical channel characteristics which existed at that time cannot be checked now due to changes over time. However a sensitivity analysis to check on the effect of possible errors in the channel characteristics was performed for the 1882 flood. Various possible combinations of channel slope and Mannings 'n' (channel roughness) were chosen and the corresponding discharge computed. The results are shown on Table 1. The Mannings 'n' of 0.0236 used by PFRA in their calculations is at the lower end of what the literature (Chow 1959) suggests for large natural streams. Backwater runs done during the FDR Study (1981) indicated that for the 1976 flood, values of 'n' in the 0.030 to 0.036 range are more likely. In terms of slope of the river surface, it is possible that the value of 0.000236 used in the PRFA calculations may be too shallow. A somewhat greater

slope of 0.000388 may be more realistic due to the greater percentage of overbank flow for floods greater than that of 1923. A review of the reach from 1st Street to the CPR bridge reveals that more than half of the flow occurs in the overbank sections of the river for floods of 1976 magnitude and this would further increase for floods as large as 1882. The energy slope increases with the overbank flow. The cross-country route (red line) shown on Figure 1, with a slope of 0.000388, may be more representative for 1882. Table 1 shows that a large range of peak flows for 1882 is possible depending on the choice of Mannings 'n' and the river slope. However the most favoured values of 0.030 for 'n' and 0.000388 for slope produce a peak flow of 43,500 cfs, which is almost identical to that computed by PFRA in the 1952 report.

Another check on the validity of the peak flow estimates is possible using extrapolations of stage-discharge relationships or rating curves. This is often done using a log scale for the discharge, but can also be done using an arithmetic scale. Figure 3A shows a log-scale extrapolation while Figure 3B shows the arithmetic scale. As indicated, it is difficult to obtain a line which fits all the points. The points for 1976, 1995 and 1882 all plot above a line fitting 1902, 1904 and 1923. It is possible to draw a line fitting all the floods up to 1923 inclusive as shown by the dashed blue line on Figure 3A. This suggests that there has been a significant change in the conveyance capacity of the river between 1923 and 1976, possibly due to sedimentation or encroachment or both. Figure 3C shows a plot of rating curves for the 1882-1923 era and the 1976-2006 era which confirms the shift. The rating curve extensions fitting the floods prior to 1923 (Figure 3C) and the blue line on Figure 2A suggest that the estimated peak flows for 1882, 1902, 1904 are reasonable and consistent.

5. FREQUENCY ANALYSIS OF PEAK FLOWS

Frequency analyses of both natural and regulated peak flows listed in Sections 1 and 2 of this report were performed using the standard Log-Pierson Type 3 frequency analysis program used by many water resource agencies in North America. The method ranks the events, determines plotting positions and draws a curve relating discharge to flood frequency based on a selected skew coefficient. The skew coefficient defines the shape of the curve and may be adjusted to obtain a 'best fit'; however it must remain within guidelines determined by scientific literature and experience.

The frequency analysis package used (USACE HEC's FFA) has a particular algorithm for assigning plotting positions based on the largest historical peak and its year of occurrence. The year in which an anecdotal flood occurred is very important as is the magnitude of the event.

A frequency plot of the regulated peak flows for the Assiniboine River at Brandon, including anecdotal floods, is shown on Figure 4. The skew coefficient was adjusted to achieve a best fit for the period of recorded peaks from 1906 to 2005 with emphasis on the floods of 1976 and 1995. It is incidental that the anecdotal floods fit the curve quite well and this again suggests that the natural and regulated anecdotal flood peak estimates are reasonably accurate

The frequency analysis of natural peak flows at Brandon indicates a 1% or 100 year flood peak of 34,300 cfs. The frequency analysis for controlled flows indicates a 100 year peak discharge of 27,700 cfs.

6. PEAK FLOWS FROM SOURCE AREAS

A rough check on the potential for the Assiniboine River to produce large controlled floods at Brandon is possible by consideration of recorded peak flows from the three main source areas, namely the sub-basin upstream of Shellmouth, the Qu'Appelle River and the remaining local area from Shellmouth to Brandon. The location of these areas is shown on Figure 5. The largest recorded peak flows from these sub-basins in the past 85 years are as follows

	Shellmouth (regulated)	Qu'Appelle	Local
Largest	13600	8500	21800
2 nd largest	12200	5900	20300
3 rd largest	6200	5550	19500

The three source areas seldom produce very high flows during the same runoff event but it is not unlikely from a meteorological perspective that they could occasionally produce a flow among the top three recorded values for a given runoff event. Due to the large amounts of flood storage in the large Assiniboine and Qu'Appelle valleys, flood crests tend to be broad and therefore the chance of coincidence of high flows from the three areas is

increased. Even the third largest events add up to a controlled crest of at least 31,000 cfs at Brandon. Applying some reduction of the peaks for less than perfect coincidence during the same event, it is still quite possible that a peak of 25,000-30,000 cfs could occur at Brandon about once every hundred years on average. The controlled peak of 27,700 cfs computed from frequency analysis therefore seems very reasonable.

7. CONCLUSIONS

The 100 year regulated flood for the Assiniboine River at Brandon has been updated based on flows for the period from 1906 to 2005 and the anecdotal floods of 1882, 1902 and 1904. The updated estimate of the 1% (100 year return period) flood discharge at Brandon is 27,700 cubic feet per second or 784.4 cubic metres per second. This analysis includes updated simulations of Shellmouth Reservoir operations based on a 2002 study.

The 24 % increase in the design flood estimate from that of the 1981 FDR study is based largely on inclusion of anecdotal floods. Investigations by MWS have shown that the estimated peak stages and flows for these floods as reported in the early literature appear to be reasonably accurate. It is therefore concluded that the increase in the design peak flow for Brandon, as reported herein, is justified and should be adopted.

8. RECOMMENDATIONS

i) It is recommended that the MWS frequency curve of controlled flows for the Assiniboine River at Brandon, dated June, 2006 be used for design purposes in Brandon.

ii) It is recommended that the MWS consult with the City of Brandon to determine whether any further hydraulic analysis is required and to engage in such studies as necessary. An updated hydraulic analysis would determine the implications of the updated 100 year flood discharge on peak water levels in the City of Brandon. Such an analysis should include the effects of developments in the river valley portion of Brandon since the previous analysis in the 1981 FDR study.

iii) It is recommended that frequency analyses at other locations on the Assiniboine River be reviewed based on inclusion of anecdotal flood information.

Acknowledgements:

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The authors wish to acknowledge the valuable information compiled by PFRA in Appendix 1--Hydrology Study--Volume II of its 1952 report "Report--Conservation and Flood Control--Assiniboine River". They further acknowledge Water Survey of Canada and its predecessor, the Water Resources Division, Department of Resources and Development for providing data on peak flows and levels for the Assiniboine River at Brandon; the City of Brandon for providing information on conditions during the floods of 1976 and 1995; the assistance of the Canadian Pacific Railway in providing historical water levels at their crossings at Brandon and Manitoba's Transportation and Government Services in surveying the 1922 peak water level at the CPR crossing.

(1) **Duane Kelln**, P. Eng., Hydrologist--performed the frequency analysis of flows and prepared an internal preliminary report on the updated 100 year flood at Brandon.

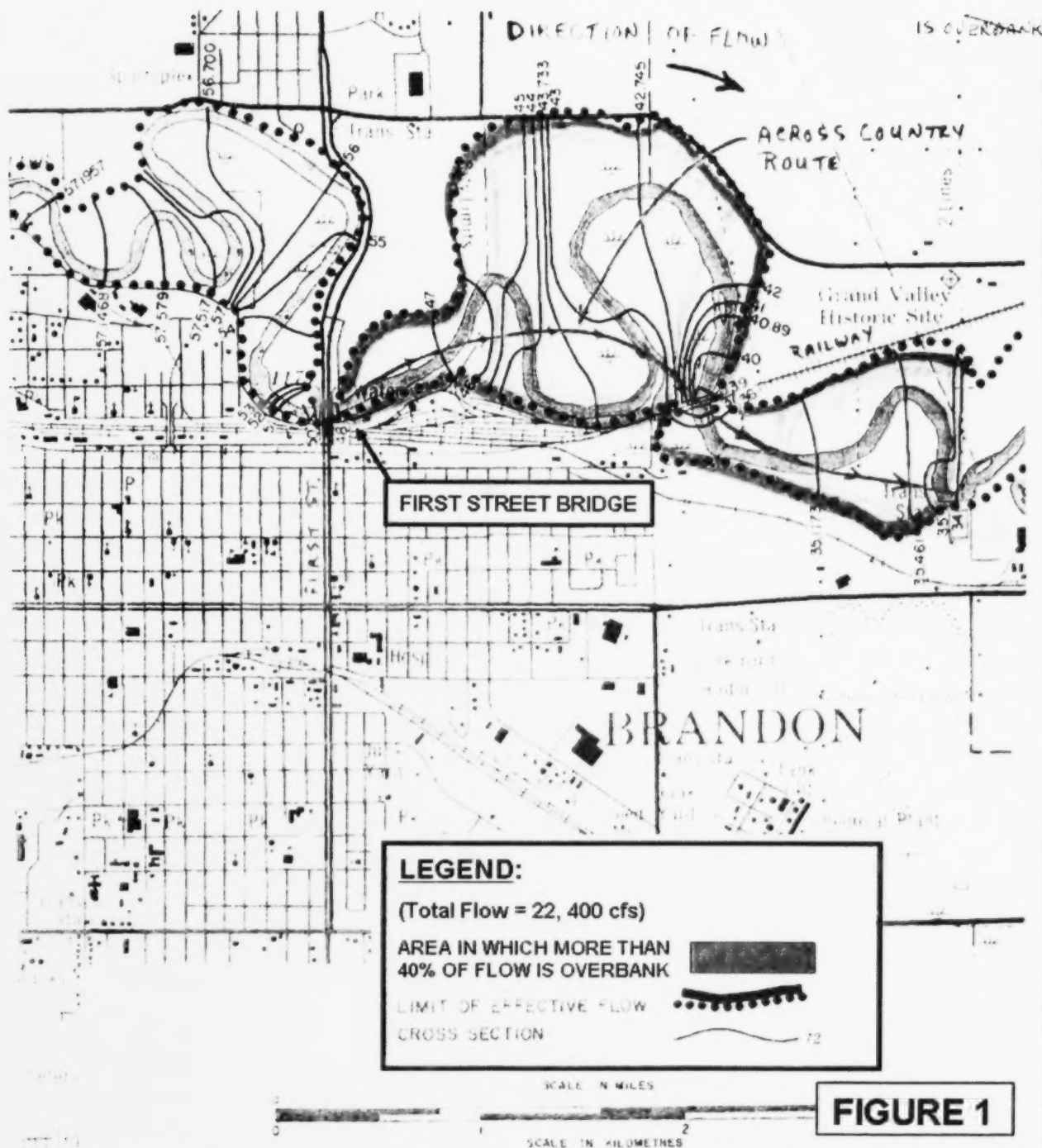
(2) **Bob Harrison**, P Eng. Senior Hydrologist-- simulated the Shellmouth Reservoir operations and computed the regulated flows for Brandon.

(3) **Alf Warkentin**, Hydrometeorologist, Senior Hydrologic Forecaster--reviewed and validated the peak levels and flows for anecdotal floods and drafted the final report.

TABLE 1. ANALYSIS OF 1882 PEAK ESTIMATE BY COMPARING VARIOUS COMBINATIONS OF SLOPE AND MANNING'S N

TRIAL NO.	HYDRAULIC			CALCULATED Q			COMMENTS ON SLOPE CALCULATION
	AREA	RADIUS	SLOPE *	MANNINGS 'N' *	(CFS)	(CMS)	
1	7180	15.45	0.00044	0.021	66,100	1,870	From Dwg# FL-1008 water surface profile u/s of First St Bridge
2	7180	15.45	0.00044	0.0236	58,800	1,670	From Dwg# FL-1008 water surface profile u/s of First St Bridge.
3	7180	15.45	0.00044	0.030	46,300	1,310	From Dwg# FL-1008 water surface profile u/s of First St Bridge
4	7180	15.45	0.00044	0.036	38,600	1,090	From Dwg# FL-1008 water surface profile u/s of First St Bridge.
5	7180	15.45	0.00044	0.050	27,800	790	From Dwg# FL-1008 water surface profile u/s of First St Bridge.
6	7180	15.45	0.000388	0.021	62,100	1,760	FDR (1981)-flow across country- d/s of First St bridge
7	7180	15.45	0.000388	0.0236	55,200	1,560	FDR (1981)-flow across country- d/s of First St bridge
8	7180	15.45	0.000388	0.030	43,500	1,230	FDR (1981)-flow across country- d/s of First St bridge
9	7180	15.45	0.000388	0.036	36,200	1,030	FDR (1981)-flow across country- d/s of First St bridge
10	7180	15.45	0.000388	0.050	26,100	740	FDR (1981)-flow across country- d/s of First St bridge
11	7180	15.45	0.000236	0.021	48,400	1,370	PFRA (1952) ORIGINAL ESTIMATE OF SLOPE
12	7180	15.45	0.000236	0.0236	43,100	1,220	PFRA (1952) ORIGINAL ESTIMATE OF SLOPE and FLOW
13	7180	15.45	0.000236	0.030	33,900	960	PFRA (1952) ORIGINAL ESTIMATE OF SLOPE
14	7180	15.45	0.000236	0.036	28,200	800	PFRA (1952) ORIGINAL ESTIMATE OF SLOPE
15	7180	15.45	0.000236	0.050	20,300	570	PFRA (1952) ORIGINAL ESTIMATE OF SLOPE
11	7180	15.45	0.000141	0.021	37,400	1,060	FDR (1981)-flow in channel- d/s of First St bridge
12	7180	15.45	0.000141	0.0236	33,300	940	FDR (1981)-flow in channel- d/s of First St bridge
13	7180	15.45	0.000141	0.030	26,200	740	FDR (1981)-flow in channel- d/s of First St bridge
14	7180	15.45	0.000141	0.036	21,800	620	FDR (1981)-flow in channel- d/s of First St bridge
15	7180	15.45	0.000141	0.050	15,700	440	FDR (1981)-flow in channel- d/s of First St bridge

* NOTE: MANNING'S ROUGHNESS COEFFICIENT OF 0.0236 AND SLOPE OF 0.000236 WERE CALCULATED BY PFRA (1952) USING FLOW AND SLOPE DATA RECORDED DURING 1923 FLOOD. THESE PARAMETERS PRODUCED A PEAK FLOW ESTIMATE OF 43,100 CFS FOR 1882.



PROVINCE OF MANITOBA
 DEPARTMENT OF NATURAL RESOURCES
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CANADA-MANITOBA FLOOD DAMAGE REDUCTION PROGRAM
 BRANDON AREA FLOOD RISK STUDY
 LOCATION OF CROSS SECTIONS
 MODEL I

Correlation of Brandon Annual Peaks -- Unregulated versus Regulated

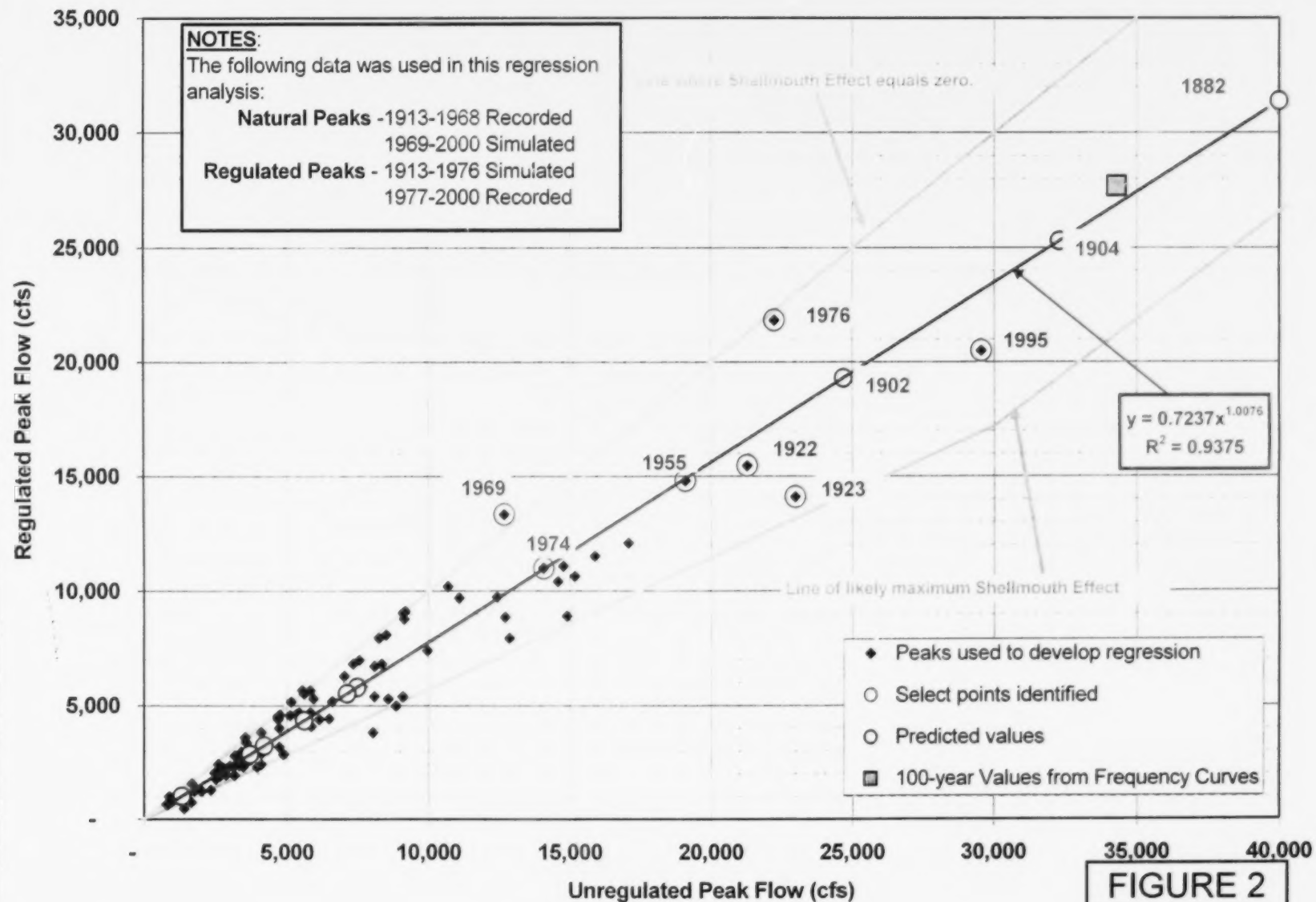


FIGURE 2

COMPARISON OF THE RATING CURVES FOR ASSINIBOINE RIVER AT BRANDON FIRST STREET
BRIDGE TO RECORDED PEAKS AND HISTORIC PEAKS DETERMINED BY PFRA IN 1952 - LOG
EXTRAPOLATION

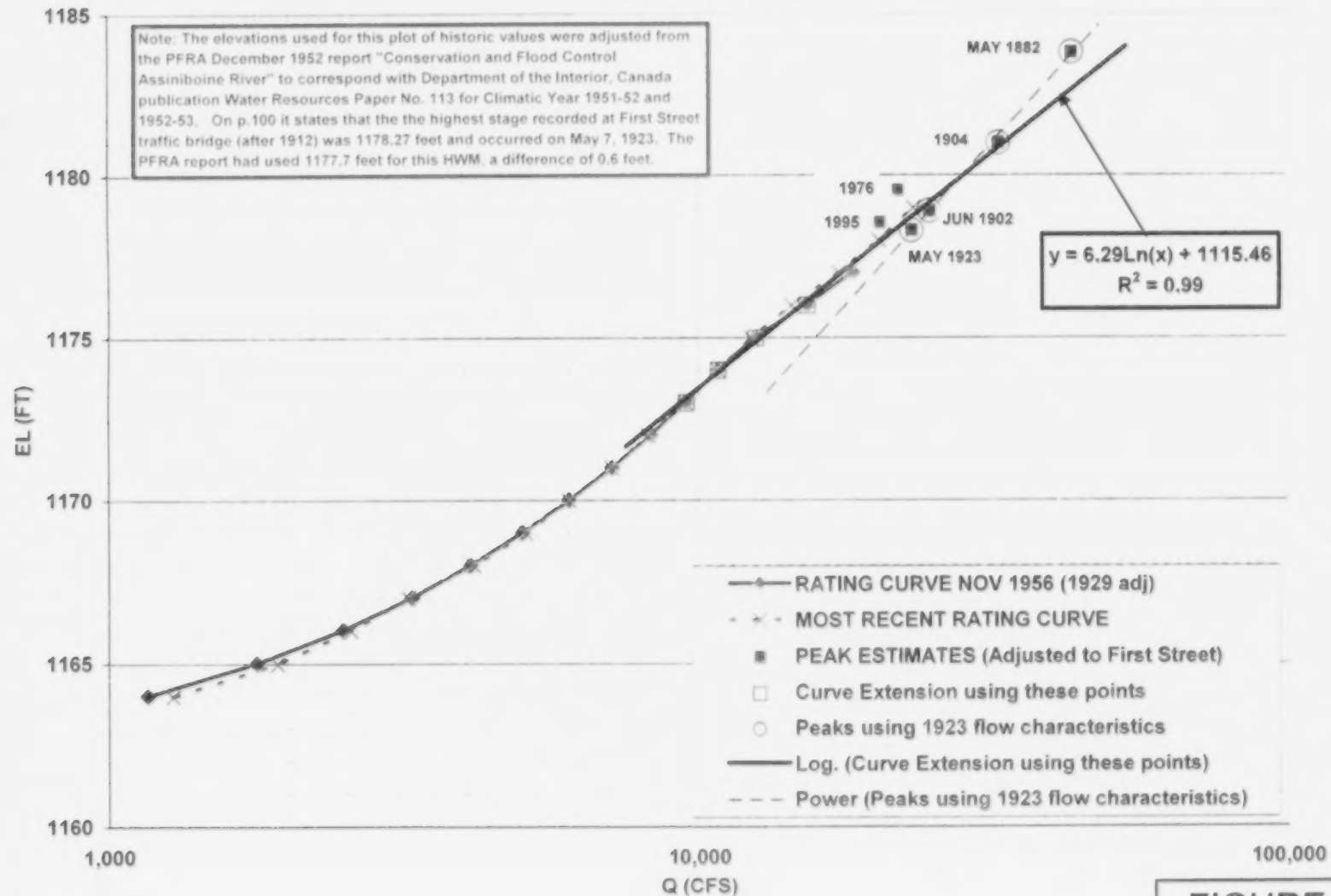


FIGURE 3A

**COMPARISON OF THE RATING CURVES FOR ASSINIBOINE RIVER AT BRANDON FIRST STREET
BRIDGE TO RECORDED PEAKS AND HISTORIC PEAKS DETERMINED BY PFRA IN 1952 - ARITHMETIC**

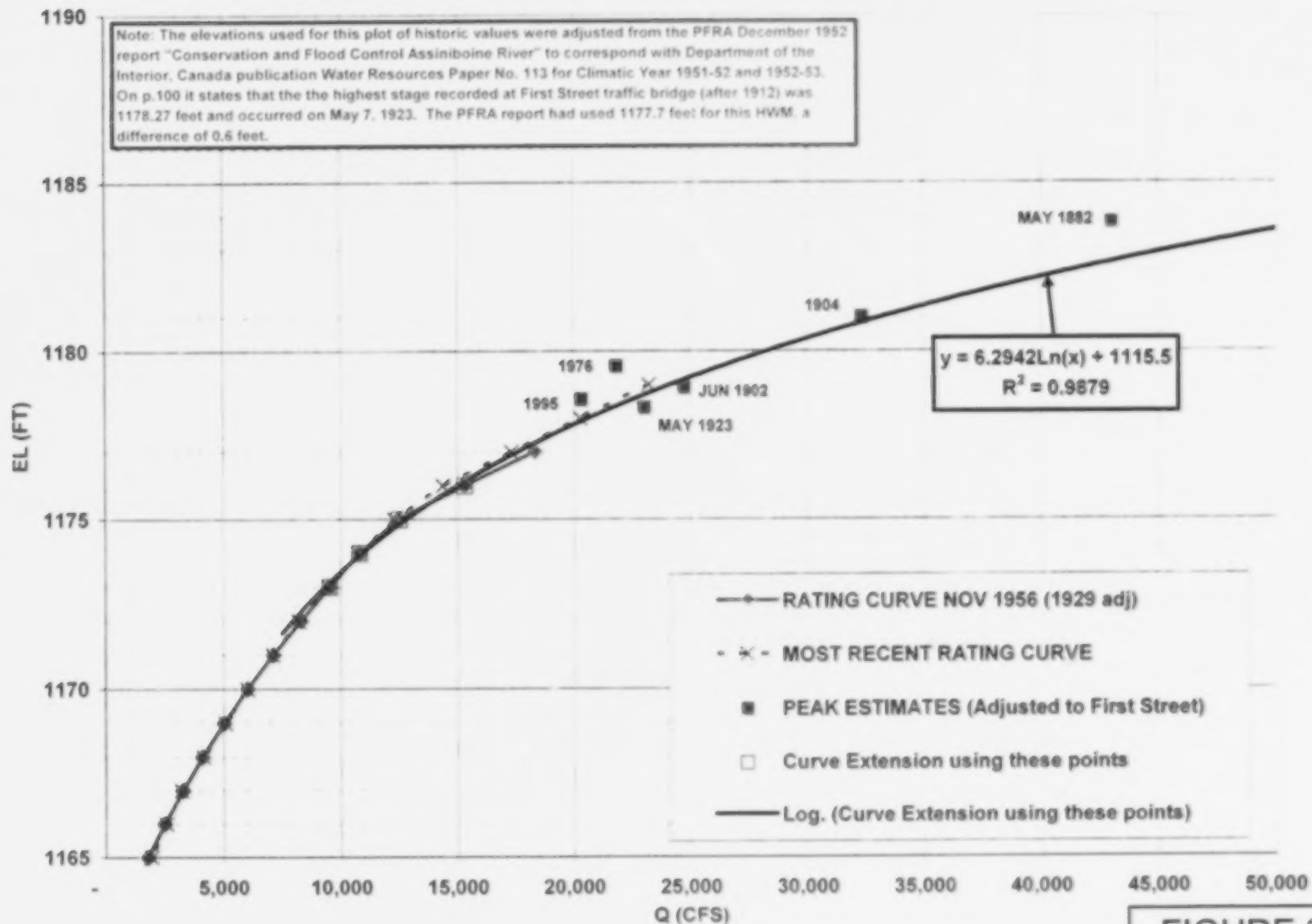


FIGURE 3B

STAGE - DISCHARGE CURVES
ASSINIBOINE RIVER AT FIRST STREET BRANDON, MAN.

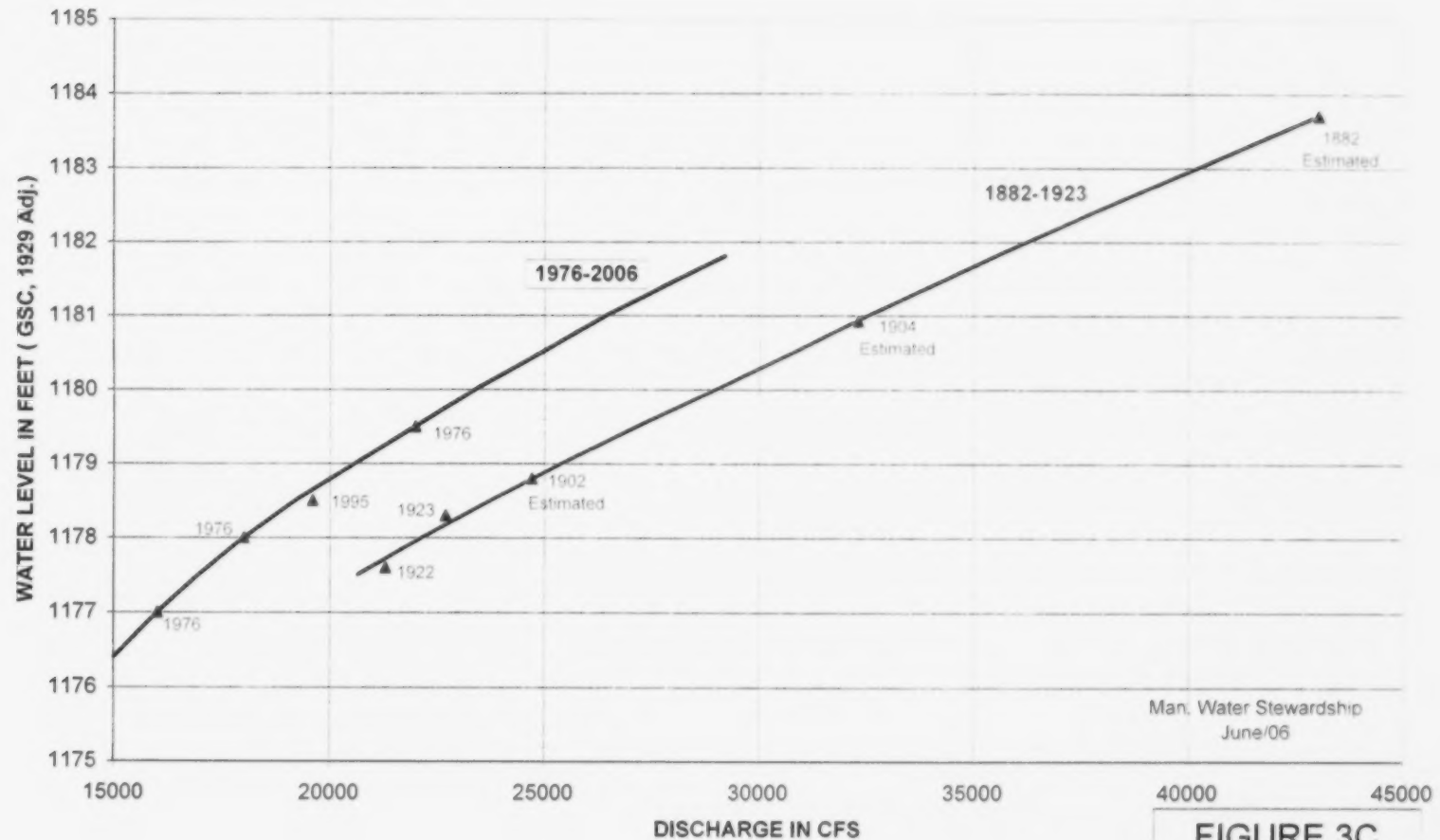
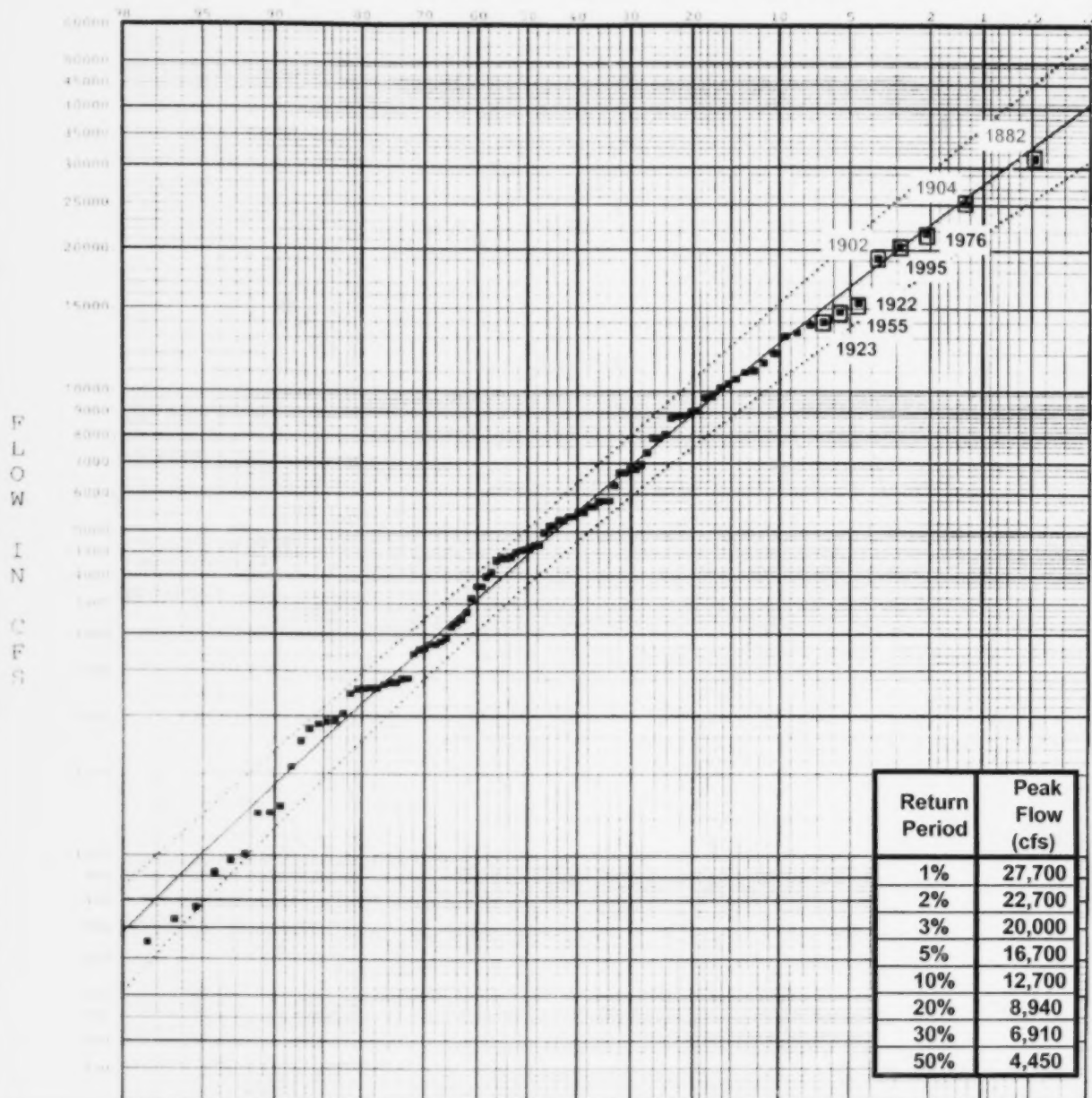


FIGURE 3C

EXCEEDANCE FREQUENCY IN PERCENT



Return Period	Peak Flow (cfs)
1%	27,700
2%	22,700
3%	20,000
5%	16,700
10%	12,700
20%	8,940
30%	6,910
50%	4,450

— FLOW Frequency (without Exp. Prob.)
 ■ User Defined Positions
 5% and 95% Confidence Limits

MANITOBA WATER STEWARDSHIP
 ASSINIBOINE RIVER AT BRANDON - REGULATED
 D.E. KELLIN, JUNE 2006

Approved: *[Signature]*
 Date: *[Date]*
 DATA FOR YEARS INCLUDED:
 1882, 1902, 1904, 1906, 2005

FIGURE 4

MAJOR SUB-BASINS -- ASSINIBOINE RIVER UPSTREAM OF BRANDON

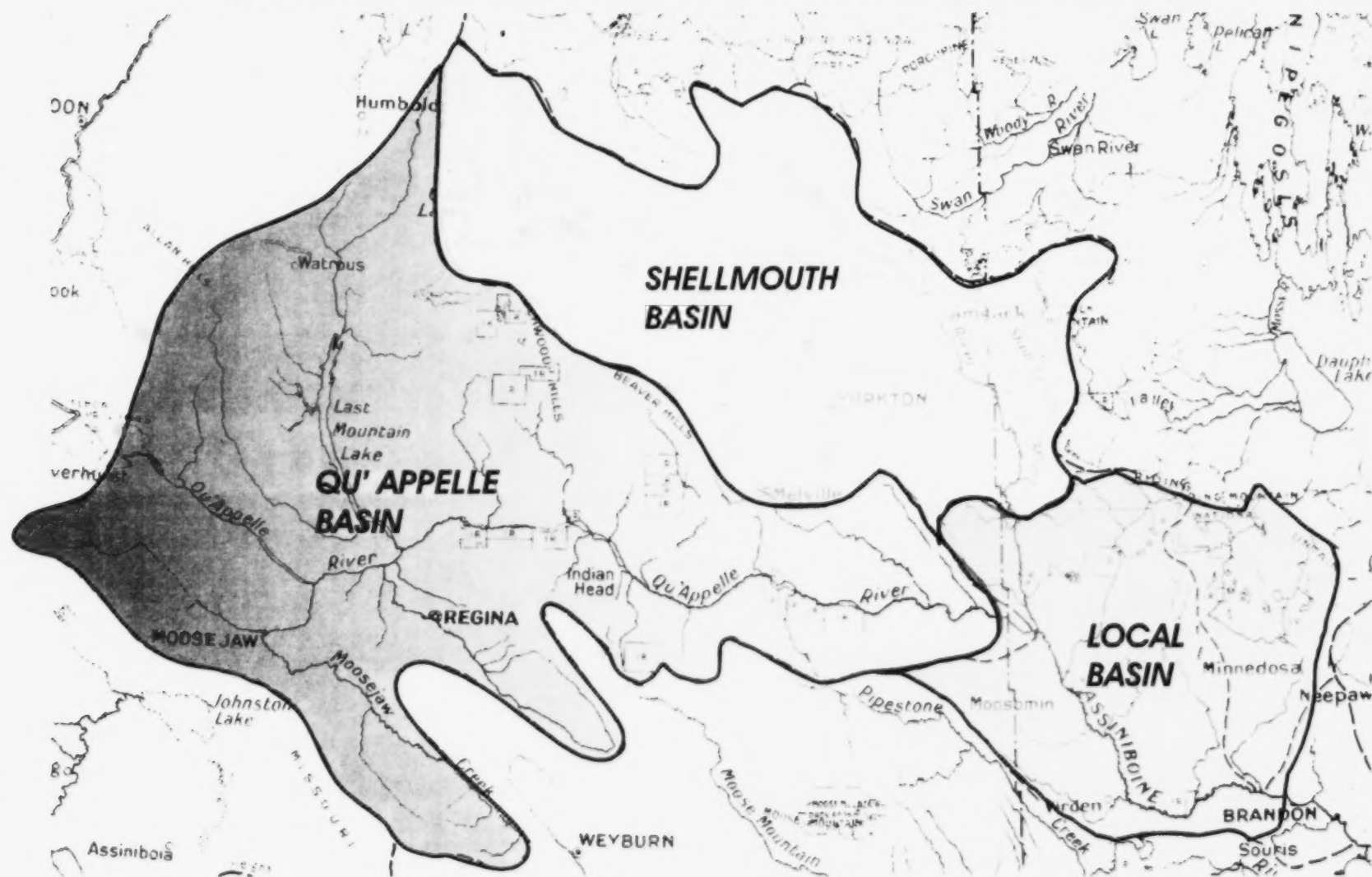


FIGURE 5



